

By Thomas B. Fryer* and Gordon J. Deboo*

13 p [1463] 13 p up Submitted for publication

Summary - A miniature, high-performance, multipurpose amplifier for bio-medical applications has been developed.

The circuit takes advantage of new, high reliability silicon transistors which feature low noise and the capability of operating with low current. The need for such an amplifier. its design and performance are discussed.

INTRODUCTION

The large amount of research in the life sciences now being conducted at NASA's Ames Research Center at Moffett Field, California, resulted in a number of requirements for an improved bio-medical amplifier. Although the amplifier was designed for a space experiment it has already found wide use in ground applications. It should be of great value anywhere a high performance amplifier is required in a compact, low power, rugged, and reliable package.

Bio-medical amplifiers have been available for many years and a number of circuits have appeared in the literature. Commercially available amplifiers meeting all the requirements for physiological work are too bulky and require too much power for many applications. Amplifiers which are small enough generally unduly compromise one or more of the specifications. For example, the input impedance might be low, giving rise to calibration errors with changes in tissue impedance, or the output impedance might be high resulting in matching problems when feeding relatively low impedance devices, such as are found in some telemetry systems. Frequency

*Ames Research Center, Moffett Field, California

N 65 88534

(ACCESSION NUMBER)

13
(PAGES)

TMX-51506
(NASA CR OR TMX OR AD NUMBER)

(THRU)

(CODE)

(CATEGORY)

response, especially at the low end, is often not adequate for faithful reproduction of such waveforms as occur, for example, in electrocardiograph signals.

The amplifier to be described is small and compact, without sacrificing important requirements.

REQUIREMENTS

The ideal requirements for a bio-medical amplifier can be summarized as follows:

1. High input impedance
2. Low output impedance
3. Low noise
4. Good low-frequency response
5. Differential input
6. High common-mode rejection

Some additional requirements are imposed if the application is for space use, portable battery operation, or as a preamplifier adjacent to the subject, namely:

7. Low power
8. Small size
9. Single-ended output for a compatibility with standard telemetry equipment, while maintaining high common-mode rejection
10. Rugged construction
11. Use of high reliability components
12. Performance maintained in an environment with variable temperature and humidity.

It has been shown¹ that electrode-to-body impedances of up to 100 kilohms can be expected in routine practice on humans. To account for

-3-

such factors as use of different kinds of animals and prolonged use of electrodes,² it would seem that an input impedance of 100 times 100 kilohms, or 10 megohms is necessary.

In order to be compatible with a variety of output devices such as recorders, subcarrier oscillators, transmitters, etc., and to minimize pickup due to interconnecting cables, an output impedance of less than 100 ohms is desirable.

The equivalent input noise should be as low as possible. With a bandwidth of 100 cps an equivalent input noise level of 0.5 microvolt rms is satisfactory for most purposes.

In order to pass all the information being monitored, a dc amplifier should be used. However, shifting baselines due to changing electrode potentials, perspiration and dc body potentials, plus the fact that practically all the relevant data in the electrocardiogram, electromyogram, and electroencephalogram are above 0.2 cps mean that there are advantages in using an ac amplifier, although the number of capacitor couplings should be minimized to reduce overload blocking effects.

With grounded systems a differential input is necessary to obtain high common-mode rejection. Experience has shown that a common-mode rejection ratio of 80 db or greater is sufficient for most practical purposes.

CIRCUIT DESIGN

A block diagram of the amplifier designed to meet the above requirements appears in Fig. 1, and the circuit diagram is shown in Fig. 2.

Transistors Q1 and Q2 are input emitter followers which provide an input impedance of greater than 10 megohms from each input to ground when loaded by Q3, Q4, and their bias networks. Field effect transistors were considered for Q1 and Q2, because of their high input impedance, but eventually the

2N2484, a silicon planar NPN transistor was selected. The equivalent input noise of any transistor has two components, voltage and current. Since the amplifier is to be used with low-impedance sources, the transistor having the lowest equivalent voltage noise generator should be used. Although field effect transistors have an extremely low current noise, their voltage noise was found to be slightly inferior to that of the 2N2484, the high current gain of which resulted in a more than adequate input impedance.

Capacitors C1 and C2 provide isolation for the second stage from slowly changing voltages appearing at the input as a result of body-to-electrode potentials.

In order to maintain high common-mode rejection it is essential that common-mode signals be attenuated equally to avoid producing signal-mode voltages at the bases of Q3 and Q4 and, in the interest of miniaturization and simplicity in use, component selection was preferable to having adjustable controls. The time constants C1R3 and C2R4 are therefore selected equal within 1 percent. For the same reason Q1 and Q2 are selected for equal gain and, in order to obtain a high input impedance, for a current gain in excess of 300. The Fairchild 2N2484 has a maximum current gain of 600 at the current levels used in this amplifier and, therefore, is satisfactory for the purpose.

Transistors Q3 and Q4 form a differential amplifier with constant-current generator Q5 providing the high common emitter impedance necessary to obtain good common-mode rejection. This stage was used as a differential to single-ended converter which means that the common-mode rejection depends on a high ratio of emitter to collector impedances rather than mere balance as in differential-in to differential-out stages,

although balancing of Q3 and Q4 was necessary to obtain maximum common-mode rejection.

Since high gain is required from Q3 and Q4 to raise the signal above any noise contributed by later stages, an emitter follower Q6 is employed to couple to the relatively low input impedance of the next stage. The differential to single-ended gain is 40.

Transistors Q7, Q8, Q9, and Q10 comprise an amplifier of the form shown in Fig. 1. "A" is an amplifier having a voltage gain large compared with R_{L6}/R_{L1} . This results in a circuit with a gain equal to R_{L6}/R_{L1} (equal to 25 in this case) for ac signals, zero for dc signals, and unity for the equivalent drift of amplifier A. The advantage of the circuit is that no capacitor is required to remove dc offsets from the output, which is stable at about ground potential. This keeps the number of capacitor coupling stages in the amplifier down to only 2. An additional feature of this type of circuit is its low output impedance, in this case below 50 ohms. Capacitor C4 can be chosen to limit the high-frequency response; for example, with a 330 pf capacitor the upper cut-off occurs at 200 cps. Capacitors C1, C2, and C3 can be selected to adjust the low-frequency cut-off; the values shown give a cut-off of 0.15 cps.

MEASURED CIRCUIT DATA

The measured performance of the amplifier is as follows:

Gain	1000
Input impedance	24 megohms differential
Output impedance	25 ohms
Maximum output voltage	6 volts peak to peak into 1 megohm
	2.6 volts peak to peak into 10 kilohms

Noise referred to input	Less than 0.5 microvolt rms with 10 kilohms source and bandwidth of 0.15 cps to 100 cps
Battery drain	0.55 ma
Battery power	Less than 5 milliwatts
Maximum frequency response	0.15 cps to 10 kc/s
Common-mode rejection	25,000:1

The amplifier was used to record the amplifier noise level, an electrocardiogram, and an electroencephalogram, appearing in Fig. 3.

CONSTRUCTION

The amplifier was constructed two ways. One, shown in Fig. 4, is a cordwood, welded package 0.8 inch by 0.65 inch, by 0.35 inch, weighing 5 grams, and is intended for applications where space is at a premium. The other, shown in Fig. 5, is a standard printed circuit 2.8 inches long by 1.5 inches wide.

APPLICATION

The amplifier has been used to monitor the electroencephalogram from a monkey and electromyogram records have been made during nerve stimulation tests. These were ground tests in the process of preparation for future satellite experiments in which space, weight, and power will be important factors. The amplifier has also been used to amplify electrocardiogram signals from pilots undergoing exercise tests and centrifuge tests. In this case the amplifier was a part of a bio-medical package worn by the subject to measure a variety of physiological data.

Past experience in the design of electronic equipment for satellite experiments indicates that this amplifier should perform very satisfactorily

in a space environment. The need for small size and low power consumption has always been a problem in space experiments and the design ideally meets these needs, while still maintaining the accuracy, low noise level, etc., possible with conventional laboratory equipment.

REFERENCES

¹O. H. Schmidt, M. Okajima, and M. Blaug, "Skin Preparation and Electrocardiographic Lead Impedance," Int. Conference on Medical Electronics, New York, July 1961.

²N. P. Thompson, and J. Patterson, "Solid State Bridge Contact Electrodes," Symposium for Bio-Medical Engineering, San Diego, Calif., 1963.

-8-
FIGURE TITLES

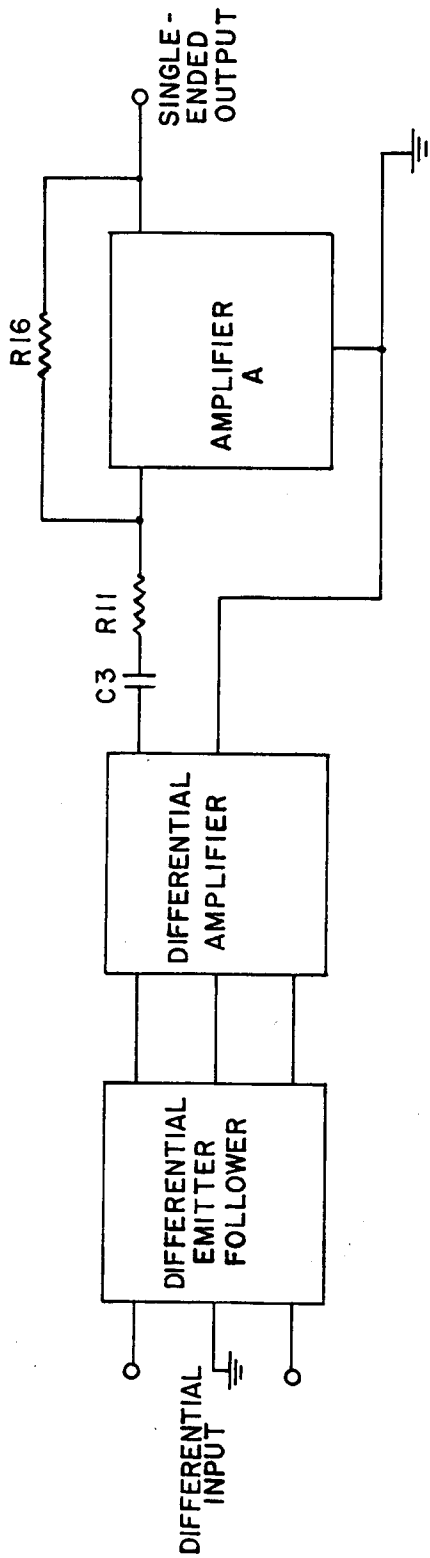
Fig. 1.- Bio-medical amplifier block diagram.

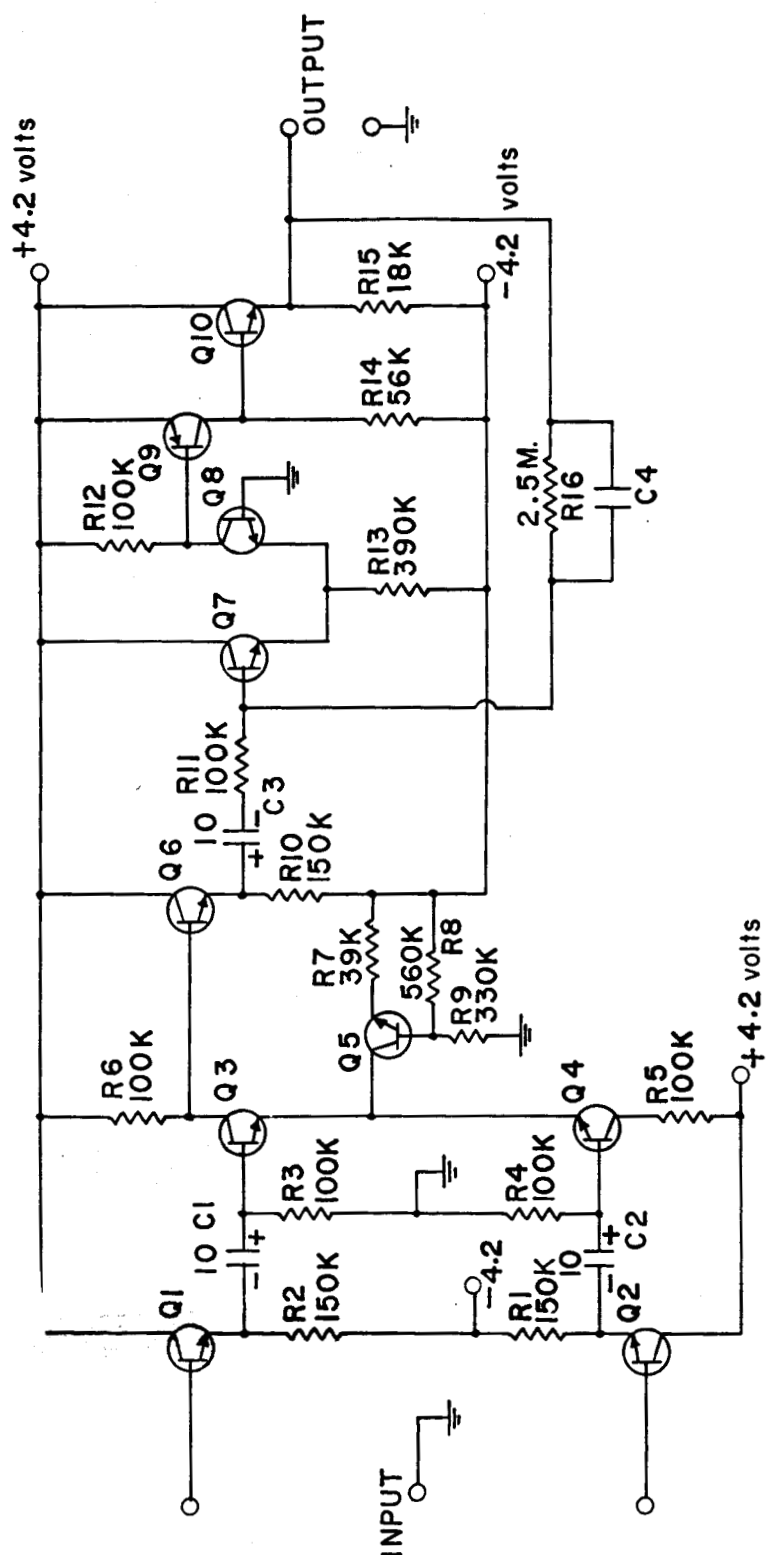
Fig. 2.- Bio-medical amplifier circuit diagram.

Fig. 3.- Typical amplifier noise level, ECG, and EEG records using the described amplifier.

Fig. 4.- Welded cordwood version of amplifier.

Fig. 5.- Printed circuit version of amplifier.





NOTES: 1 ALL RESISTORS IN OHMS.

2 K=X10, M=X10⁶

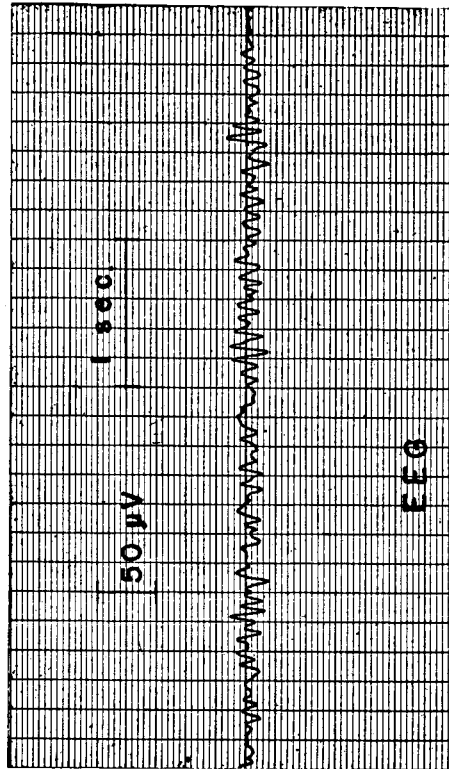
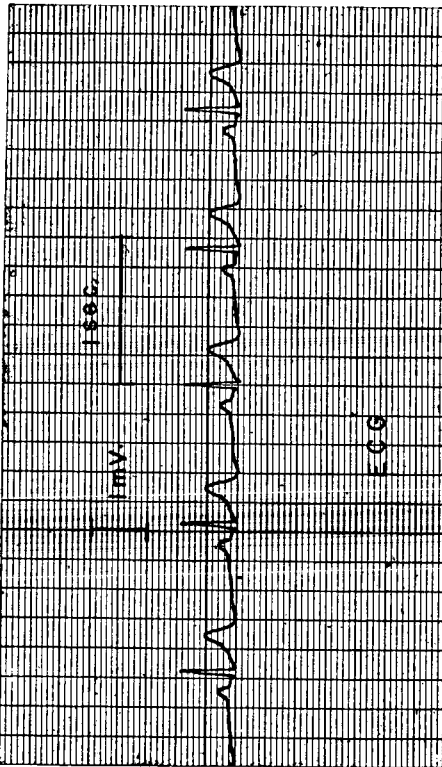
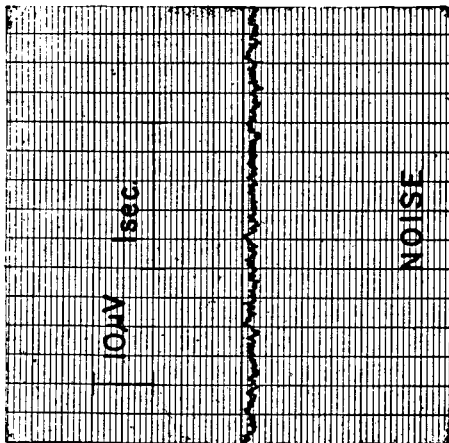
3 ALL CAPACITORS IN MICROFARADS.

4 TRANSISTORS: Q1-Q5, 7 & 8=FM2484. (2N2484 IN TO-46 CASE)

5 Q6 & 10=FM1613. (2N1613 IN TO-46 CASE)

6 Q9=FM1132. (2N1132 IN TO-46 CASE)

Fig 2



Handwritten signature

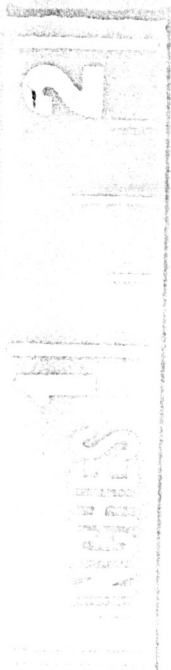
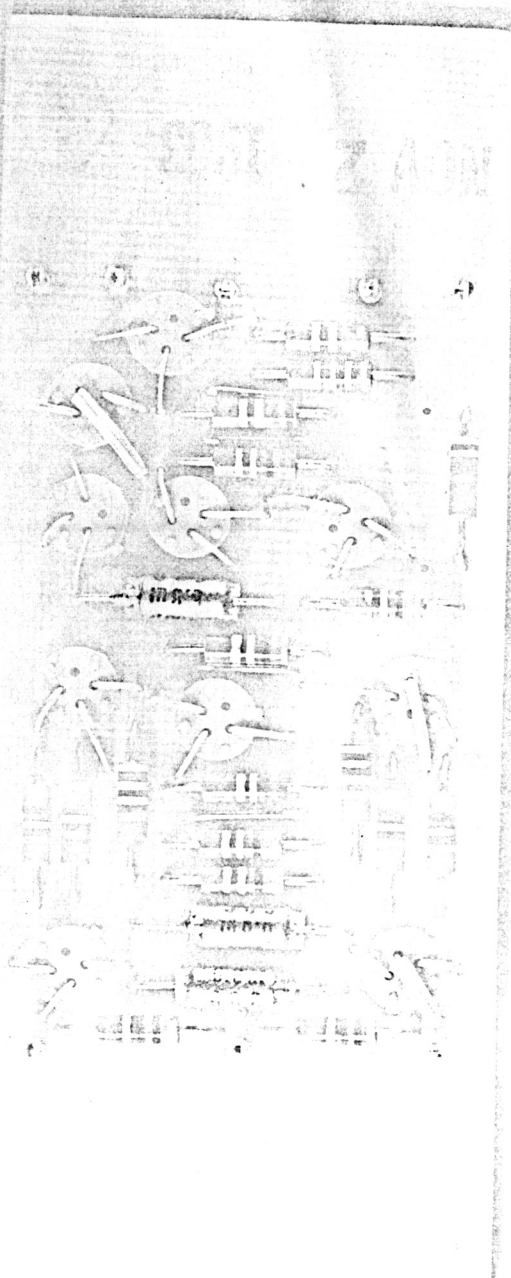
XERO COPY

XERO COPY

XERO COPY

XERO COPY

A-31006



July 5

A-31699

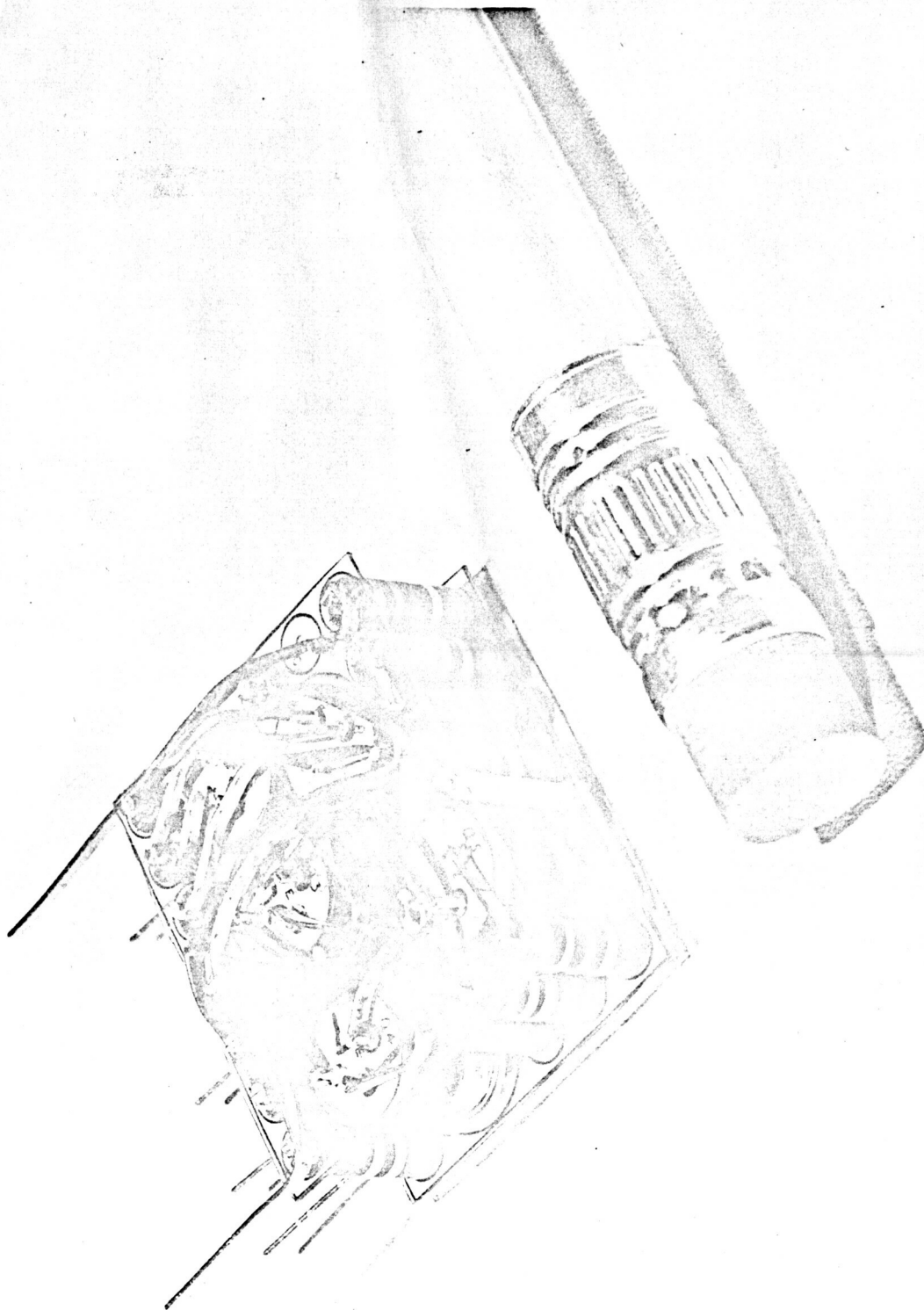


Fig 4